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The advantage of ODRAM relative to existing memory technologies is speed and capacity for a competitive price. The unit cost in early production will be in the range of $20,000-25,000 for 100 Gigabytes of capacity. The nonmechancial access of ODRAM will enable much higher data throughput rates and much faster access to small records in large databases. ODRAM offers three orders of magnitude improvement in data access rates relative to mechanically-accessed memory technologies.

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Optical Random Access Memory

Alan E. Johnson, Eric S. Maniloff, Thomas W. Mossberg

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Templex Technology Corporation
Final Report of March 25, 1998
Project Title: " Optical Random Access Memory"

Background and Introduction

Data storage is a key component of any nontrivial computing system. Achievable computational performance strongly reflects limitations inherent in the storage technologies currently available. Crucial performance characteristics of data storage devices include

- random access latency time
- peak data transfer rate,
- total capacity
- persistence time
- cost per unit performance.

In current desktop, server and high performance computing applications, overall data storage functionality is achieved through a combination of technologies, wherein the strengths of one technology compensate for the weaknesses of others. This situation has arisen because no single storage technology can provide optimal performance in all arenas. Two memory technologies currently dominate high performance storage applications: semiconductor RAM and mechanically accessed magnetic devices. Other technologies are important for archival backup (tape) and distribution (CD-ROM). Semiconductor RAM is very fast in terms of transfer rate (multi-Gigabit/second bus aggregate) and random access time (50-100 nanoseconds). However, it is expensive and usually volatile. Mechanically accessed magnetic storage devices offer enormous (up to 10 Gigabyte/unit) permanent storage for a very low price, but have very long (5-10 millisecond) random access latency times and relatively low peak transfer rates (100-200 Megabit/second serial).

The mismatch in performance (speed and capacity) between magnetic storage devices and semiconductor RAM leads to performance bottlenecks in many computational applications, especially those applications that require access to large numbers of small data records. It is exactly this bottleneck that Templex Technology is addressing through the development of a new memory technology, Optical Dynamic RAM (ODRAM). In a simple implementation, ODRAM is a two dimensional memory with data stored in an array of spatial locations. At first glance, this seems conceptually similar to standard magnetic or optical disk technology. However, in ODRAM, *many thousands of bits are stored in each and every spatial location*, through the techniques of persistent spectral hole burning and spectral holography. Up to 100,000 bits per spot are expected during our development cycle. Very preliminary university demonstrations have already achieved more that 4000 bits per spatial location. Because of the high multiplicity of bits within a single spatial address, substantial data capacities can be achieved with a relatively small number of spatial addresses.

Multi Gigabyte (50-100) capacity storage units can be implemented with entirely non-mechanical beam steering- thus providing random access times of microseconds rather than the random access times of milliseconds common in mechanically accessed magnetic disk storage technology.

ODRAM is based on two technologies, spectral holography and persistent spectral hole burning. Spectral holography refers to the recording of temporal waveform information in the frequency dimension within frequency selective recording materials. Spectral holography is effected through the spectral interference of distinct temporally structured (data encoded) light beams inside the recording material. Persistent spectral hole burning refers to the physical process of modifying the absorption profile of frequency selective materials, recording the information.

Technical Objectives of Phase I

Design, implement, and evaluate components and subsystems for development of an optical dynamic RAM. (No change to previously stated objectives).

The overall, long-term goal of Templex Technology is the integration of the recently **demonstrated** high multiplicity spectral multiplexing with **existing** beam-deflection technology to yield a high capacity, low latency, Optical Dynamic RAM. The possibility of ODRAM class memory was first suggested after the demonstrations of multi-kilobit spectral multiplexing of data at single spatial locations. Without dense spectral (or some other type of) multiplexing, it is impossible to non-mechanically access useful amounts of data with current optical beam control. The ODRAM concept integrates a variety of optical and other technologies in new combinations, subject to new constraints. Templex Technology's overall Phase I objectives were to:

- Determine the ODRAM performance levels that can be realized on a short-term basis by designing and performing an exhaustive performance analysis of an ODRAM prototype, as achievable using existing storage materials and optical support technology. These results would form the basis of Phase II SBIR work where prototypes will actually be constructed and tested.
- Determine prototype and production level costs associated with currently realizable Optical RAM devices.
- Conduct laboratory evaluation of potential high performance storage materials.
- Evaluate the probable future course of storage material development and determine Optical RAM performance when implemented with materials projected to be available.

Work Performed and Results Obtained

Our analyses of potential performance and cost structure during Phase I have been very positive. Based on these analyses, we believe that we can build a device that has an

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enormous performance advantage relative to magnetic storage media with a cost per GByte that is significantly below the cost per GByte of semiconductor DRAM. We were very encouraged by these results and have rapidly moved beyond the paper-based analyses to design and construction of an initial laboratory-level prototype, which we had originally planned to begin during Phase II. Our key findings and results are detailed below.

1) *Potential ODRAM Device Performance.* The major advantage of ODRAM relative to existing and entrenched memory technologies is a combination of speed and capacity for a competitive price. We have estimated that the unit cost in early production will be in the range of \$20,000-25,000 for 100 Gigabytes of capacity. The nonmechanical access of ODRAM will enable much higher data throughput rates and much faster access to small records in large databases. ODRAM offers up to three orders of magnitude of improvement in data access rates relative to mechanically-accessed memory technologies. The combination of nonmechanical data access and parallel data access opens the possibility of average transfer rates exceeding silicon DRAM.

Large Capacity: ODRAM achieves high storage capacity, as well as high storage density, by storing large numbers of bits in every spatial location, using a unique combination of time and frequency domain multiplexing (swept-carrier memory, see below). In brief, temporal data sequences are stored in a storage material capable of discriminating different colors of light, *i.e.*, a spectrally selective material. At the heart of ODRAM is a small crystal (on the order of $75\times75\times1$ mm^3) of a spectrally selective material, used as the recording material. This crystal is divided into separate spatial storage locations accessed by acousto-optic beam deflection. In one of the planned prototypes, whose parameters will be treated as an example, there will be 9,000,000 spatial storage locations arranged in a 3000×3000 grid filling the face of the crystal. Each individual storage location will hold 100,000 temporally multiplexed bits, yielding a capacity of more than 100 Gigabytes. In terms of storage density, this corresponds to a volume density of 160 Gigabits/cm^3 or, since the spatial cells are distributed in a two dimensional grid, an areal density of 100 Gigabits/in^2. Note that these densities are very low compared to the maximum densities achievable with the ODRAM technology, indicating that future implementations may utilize storage densities one or more orders of magnitude greater than our current targets. We note further, however, that the densities mentioned are of secondary importance compared to the overall storage capacity since it is the latter quantity that largely determines the overall cost/unit performance.

Fast Random Access Rates: ODRAM utilizes an entirely nonmechanical approach to data access. As a result, ODRAM provides random access speeds nearly 1000-fold faster than mechanically addressed data storage devices. In particular, the 9,000,000 spatial storage locations will be accessed via acousto-optic beam deflection, with a projected latency time of 20 microseconds (to be compared to the 5-10 millisecond latency of a magnetic hard drive). This 20 microsecond

latency is determined by the acoustic velocity in the acousto-optic beam deflector and is consistent with current commercially available technology. In addition to shortening the latency associated with random access, the ODRAM architecture eliminates latencies inherent in interconversion between storage and electronic bus formats. This is achieved by operating in a high-speed 64-bit parallel mode (post Phase II development extending the proposed 8-bit bus) that exploits the parallelism of optics while allowing direct interfacing with existing computer architectures. Note that future ODRAM units will be designed with more parallel channels to match wider data busses in future computers.

High Speed Average Transfer Rates: The overall data transfer rate of a memory technology is determined by both its random access latency time and its peak data transfer rate. ODRAM will offer high peak data transfer rates in addition to the short latency times discussed above. ODRAM will achieve high peak data transfer rates (on the order of 2 Gigabits/second) by parallel operation of 64 channels, each running at an electronically convenient 30 megabits/second. It is anticipated that ODRAM will eventually be implemented (post Phase II) with single channel bit rates as high as 1 Gigabit/second, and bus aggregate peak data rates of 64 Gigabits/second. Note that the optical power budget required to achieve the 64 Gigabit/second aggregate transfer rate is consistent with available laser sources. In Figure 1, we plot the average transfer rate (which is affected by both latency and peak transfer rate) as a function of record size for several technologies. For contiguous records smaller than 50 kilobytes, ***Serial*** ODRAM running at 30 megabits/second with a 20 microsecond latency offers higher average transfer rates than can be achieved with a magnetic hard drive. ***64-bit-parallel*** ODRAM offers data transfer rates orders of magnitude larger than those achievable with hard drives for any record length. Interestingly enough, even though the latency time of ODRAM is longer than silicon DRAM, the average throughput of ODRAM exceeds the average throughput of 50 nanosecond 64-bit-wide DRAM for contiguous records greater than 10 kilobytes.

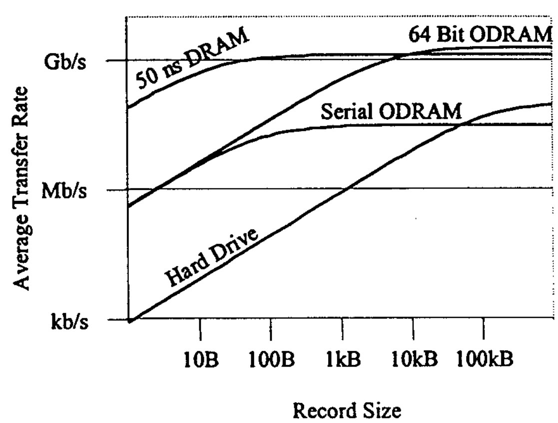

Figure 1. Average transfer rate as a function of record size. The average transfer rate for a given technology represents the total data throughput rate for that technology, taking into account the latency, the single channel bandwidth, and the number of parallel channels utilized. Here, ODRAM is assumed to have a single channel bandwidth of 30 megabits/second with a latency of 20 microseconds.

High-Speed Writing: Templex Technology's implementation of ODRAM will utilize materials that are compatible with high-speed writing. The data rates listed in the previous section apply to **both** the read and write functions. High-speed writing is possible through the use of rare-earth doped crystalline materials as the spectrally selective recording material. These materials display quantum efficiencies for writing in the range of 50%, enabling high-speed writing.

2) *Materials Characterization of $Eu^{3+}:Y_2SiO_5$.* Our preliminary literature studies (a partial summary is given in Table 1), along with extensive discussions with Rufus Cone (University of Montana), Randy Equall (Scientific Materials), and Ralph Hutcheson (Scientific Materials), led us to believe that $Eu^{3+}:Y_2SiO_5$ would be an almost ideal material for development of ODRAM, due to the long data storage time and the high potential capacity. The one disadvantage is the transition wavelength, which is not directly accessible with a commercially available diode laser.

Completion of test bed for studying $Eu^{3+}:Y_2SiO_5$. Material properties of $Eu^{3+}:Y_2SiO_5$ were studied using a combination of two and three pulse photon echoes as a function of temperature, excitation intensity, and incident polarization. Eu^{3+} substitutes into two different sites of Y_2SiO_5, leading to transitions at 580.036 nm (Site 1) and 580.209 nm (Site 2). Both sites were studied in two separate samples, a 2 mm thick sample with a 0.5% doping level and a 1 mm thick sample with a 1% doping level. The optical pulses were generated by acoustooptic chopping of the $\approx$ 580 nm output of a commercial (Coherent 699) dye laser. The $Eu^{3+}:Y_2SiO_5$ samples were cooled to subambient temperatures by contact with a cold finger that was cooled by contact with flowing liquid helium. Temperature control was maintained by resistive heating of the cold finger above the boiling point of helium. Photon echoes were detected using a Hamamatsu avalanche photodiode, model # C5331.

Photon echoes. Two pulse photon echoes were used to characterize the homogeneous and inhomogeneous linewidths, which can be used in the calculation of potential device capacity. As an example, a plot of the homogeneous linewidth, measured as a function of excitation intensity at several different temperatures is shown in Figure 2. Figure 3, which is slightly simpler, shows the measured homogeneous linewidth as a function of temperature for a single excitation intensity, 1100 W/cm^2. As expected, the linewidth increases with increasing temperature and with increasing excitation intensity. More importantly, the results of two pulse photon echo studies indicate that the effect of excitation intensity on the homogeneous linewidth (instantaneous diffusion or excitation induced dephasing) is not a function of temperature. At low temperatures, excitation induced dephasing can contribute to a large fractional change in homogeneous linewidth. However, excitation induced dephasing only causes a small fractional change at higher temperatures (~10K). The dependence of the observed linewidth on excitation intensity is linear at low intensity and shows saturation behavior at higher intensities.

Table 1. Figures of merit for representative frequency selective materials

Material	*Temperature*	*Γ_H*	*Γ_I*	*Storage Time*	*Mechanism*	*Refs*
$Eu^{3+}:Y_2SiO_5$	1.4 K	100-200 Hz	4 GHz	Hours to days	Hyperfine	1
	6 K	300-400 Hz	6-9 GHz	Hours to days		2-4
$Eu^{3+}:Y_2O_3$	4 K	3 kHz		>30 hours	Hyperfine	5
	14 K	300 kHz		5 seconds		5
	1.4 K	0.8-42 KHz				6
$Tm^{3+}:LaF_3$	1.5 K	45 kHz	4 GHz	10 ms	Metastable	7-8
Tm^{3+}:YAG	1.5 K	4 kHz		10 ms	Metastable	8
$Pr^{3+}:Y_2SiO_5$	1.4 K	1-2 kHz	3-4 GHz		Hyperfine	9
Eu^{3+}:Silicate glass	0.4-4.2 K	2 MHz-10 MHz		> 100 s at 1.2 K	Hyperfine	10
Pr^{3+}:Silicate glass	0.4-10 K	10 MHz-700 MHz		> 100 s at 1.2 K	Hyperfine and persistence	10
Eu^{3+}: β''alumina	5 K	1 GHz		2 minutes	Hyperfine	11
	110 K	10 GHz		30 minutes	Ionic motion	
Sm^{2+}:BaFCl	2 K	25 MHz	16 GHz	"permanent"	Photon gated	12
$Sm^{2+}:BaFCl_{.5}Br_{.5}$	77 K	1.4 cm^{-1}	26 cm^{-1}	"permanent"	Photon gated	13
$Sm^{2+}:SrFCl_xBr_{1-x}$	295 K	200 GHz		"permanent"	Photon gated	14
Sm^{2+}:SrFCl	77 K	0.4 cm^{-1}		"permanent"	Photon gated	15
$Sm^{2+}:SrFCl_{.5}Br_{.5}$	295 K	4 cm^{-1}	30 cm^{-1}	"permanent"	Photon gated	16
$Pr^{3+}:D^-:SrF_2$	1.6 K	<1 MHz		minutes	D^- migration	17

Table 1 References

1) R.W. Equall, Y. Sun, R.L. Cone, R.M. Macfarlane, Phys. Rev. Lett., **72**, 2179 (1994)
2) R. Yano, M. Mitsunaga, N. Uesugi, J. Opt. Soc. Am., **9**, 992 (1992)
3) R. Yano, M. Mitsunaga, N. Uesugi, Opt. Lett., **16**, 1884 (1991)
4) R. Yano, M. Mitsunaga, N. Uesugi, Opt. Lett., **16**, 1890 (1991)
5) W. R. Babbitt, A. Lezama, T.W. Mossberg, Phys. Rev. B, **39**, 1987 (1989)
6) G.P. Flinn, K.W. Jang, J. Ganem, M.L. Jones, R.S. Meltzer, R.M. Macfarlane, J. Lumin., **58**,374 (1994)
7) R.M. Macfarlane, Opt. Lett., **18**, 829 (1993)
8) R.M. Macfarlane, Opt. Lett., **18**, 1958 (1993)
9) R.W. Equall, R.L. Cone, R.M. Macfarlane, Phys. Rev. B, **52**, 3963 (1995)
10) Th. Schmidt, R.M. Macfarlane, S. Volker, Phys. Rev. B, **50**, 15707 (1994)
11) H. Yagumi, R. Yagi, S. Matsuo, M. Ishigame, Phys. Rev. B., **53**, 8283 (1996)
12) A. Winnacker, R.M. Shelby, R.M. Macfarlane, Opt. Lett., **10**, 350 (1985)
13) C. Wei, S. Huang, J. Yu, J. Lumin., **43**, 161 (1989)
14) T. Asatsuma, N. Umezu, Y. Takemoto, M. Kaneko, J. Lumin., **64**, 201 (1995)
15) J. Zhang, S. Huang, W. Qin, D. Gao, J. Yu, J. Lumin., **53**, 275 (1992)
16) N. Umezu, T. Asatsuma, Y. Takemoto, M. Kaneko, **64**, 195 (1995)
17) R.J. Reeves, R.M. Macfarlane, Phys. Rev. B, **47**, 158 (1993)

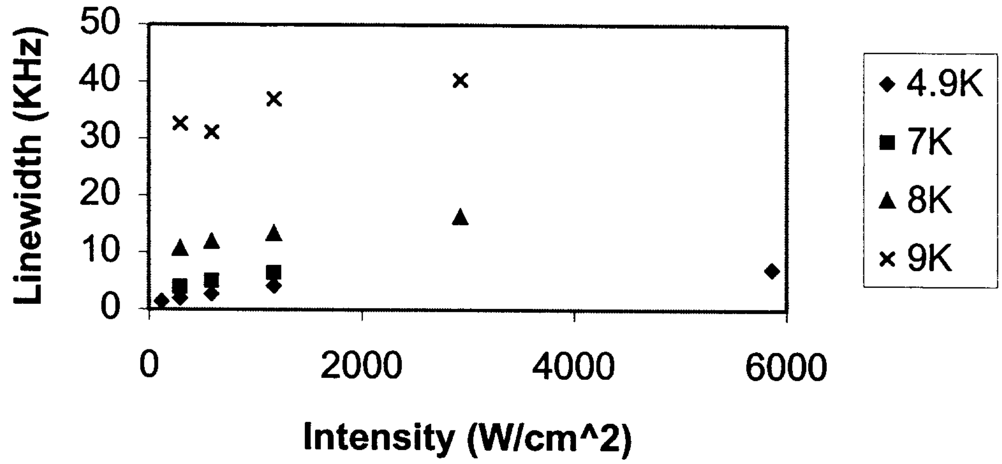

Figure 2. Homogeneous linewidth of Eu^{3+}:Y_2SiO_5 as a excitation intensity at several representative temperatures. Results shown here are for Site 1 of the 2 mm, 0.5% doped sample.

Three pulse photon echoes were performed in site 1 of the 1 mm thick 1% sample at temperatures up to 9 K. In this case, the delay times (between the second and third pulses) were varied from 25 μs to 9.5 ms. The echo intensity decreased from 306 mV at short delays to 45 mV at long delays. Note that 9.5 ms is much longer than the excited state lifetime of 1.9 ms for site 1. The ratio of the intensity at short time to the intensity at long time (relative to the excited state lifetime) indicates a quantum yield for persistent hole burning of approximately 50%. This is a very important and very encouraging result, as this high quantum yield will enable rapid writing in a practical memory device. If the quantum yield were significantly lower, as is common for many organic and inorganic molecular systems, rapid writing would not be readily achievable.

Larger signals were observed in the 2 mm thick 0.5% sample. This difference is due to a combination of a different optical polarization relative to the crystalline axes and an intrinsically higher peak optical density

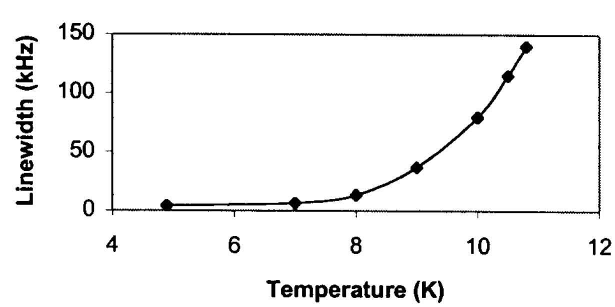

Figure 3. Linewidth as a function of temperature. Results shown here are for an excitation intensity of 1100 W/cm^2 of Site 1 of the 2 mm, 0.5% doped sample.

in the lower concentration sample. Polarization dependent studies in the 2 mm thick 0.5% sample indicate a pronounced polarization dependence, approaching an optical density of 0 at some angles in site 1.

3) *Construction a first generation laboratory prototype* for swept carrier data storage and recall in $Eu^{3+}:Y_2SiO_5$. As mentioned above, our initial Phase I results were extremely encouraging, leading us to begin laboratory prototype development during Phase I, rather than waiting for the commencement of Phase II.

The general architecture of ODRAM is summarized in Figure 4. In brief, digital data is encoded onto a frequency agile optical carrier by the data encoder and directed to a particular spatial address within the storage material by the X-Y A/O deflector. In each and every spatial location of the storage material, tens to hundreds of thousands of bits are stored with spectral holographic techniques. Readout is achieved by illumination of the appropriate spatial location with a reference wave that generates a replica of the stored optical bit-sequence. This output optical bit sequence is detected and electronically processed to yield a digital electronic data sequence.

In the first generation prototype, the laser source is a commercial ring dye laser. Sweeping is accomplished by double passing the output of the dye laser through an acoustooptic modulator with an applied RF field that is frequency chirped. Over 100 MHz of tuning is obtained in this fashion.

Data and reference beams are simultaneously generated in a second acoustooptic which is driven with two RF fields, a CW field generating the reference and a modulated field generating the data. As the reference and data beams are collinear, the generated output beam is collinear with the read beam. The

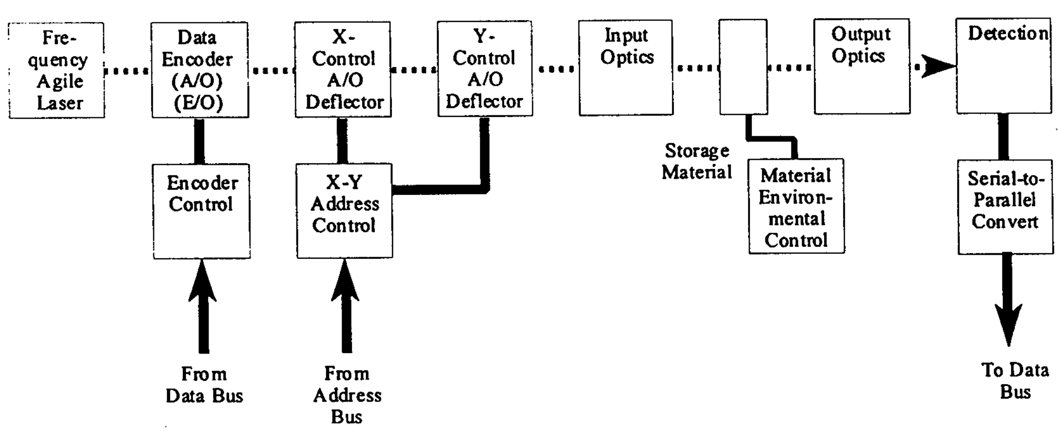

Figure 4. Block diagram of the major optical components and subsystems for ODRAM.

heterodyne beat signal between the output and read beams is detected.

The initial attempt resulted in storage and recall of 14 bits. In this case, the signal detection limit was better than 10^{-5} (ratio of reconstructed signal intensity to data intensity). In subsequent efforts we stored and recalled 200 bits, achieving a spectral density of 2 bits/MHz, matching previous University of Oregon demonstrations using Tm^{3+}:YAG. Representative data for low and high spectral density are shown in Figure 6 and Figure 5. The bit count was limited by the smallness of the currently implemented laser tuning range. It should be noted, however, that we have broken the previous record for the number of bits recalled and for the achieved spectral density using heterodyne techniques. In this measurement, the measured signal to noise ratio of the electronic signal following envelope detection was greater than 4. It is important to note, however, that the output signal intensities were over one order of magnitude lower than expected. This decrease in signal intensity was determined to be due to the acoustooptic frequency sweeping method. Upon replacement of the current system with the frequency agile laser described below, we expect to recover this order of magnitude in signal size and achieve a significantly higher signal to noise ratio. We expect signal to noise ratios of 10-15 to be easily achievable, which would correspond to raw bit error rates lower than 10^{-6}.

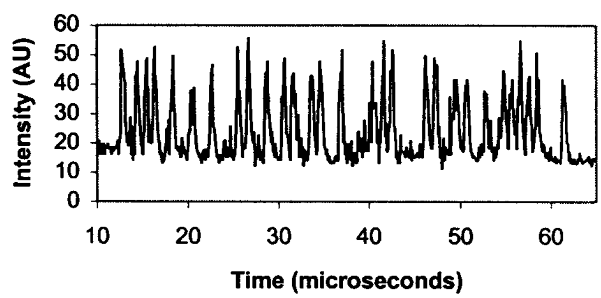

Figure 5. Representative bits stored and recalled using heterodyne detection under conditions of high spectral density.

4) *Designed and began construction of frequency agile dye laser.* The acoustooptic tuning method described above suffers from a very limited tuning range. In addition, this method introduces a small spatial beam walk, which limits the output signal size, and thereby the output signal to noise ratio. To achieve higher capacities and smaller raw bit error rates, we have designed and begun construction of a dye laser. This laser will achieve the necessary tuning range without complications of time- and frequency-dependent spatial beam walkoff. Note that a dye laser is a short term solution to the requirement of a frequency agile laser. Commercial ODRAM products will incorporate a frequency agile laser that is based on solid state and/or semiconductor components for ruggedness.

Our initial design utilized a two-mirror cavity with a birefringent filter, an etalon, and an electrooptic crystal for rapid tuning. This design was difficult due to large coupling between multiple degrees of freedom in the cavity, which did not allow

for individual optimization of any given component. In addition, the wavelength selective elements did not perform well, because they were not placed in a collimated beam, due to the lack of a collimated section in the two mirror cavity. Frequency agile performance was not achieved with this cavity design.

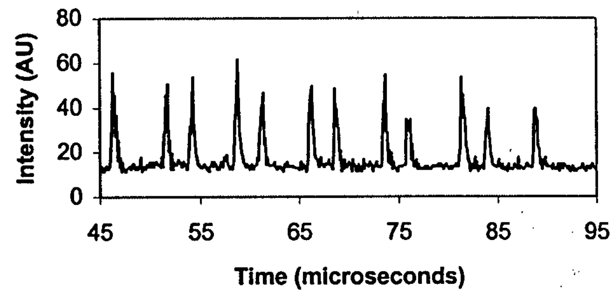

Figure 6. Representative bits stored and recalled using heterodyne detection under conditions of low spectral density.

Our new design utilizes a three-mirror cavity and allows for individual optimization of every component. In addition, the wavelength selective elements are placed in a collimated region of the cavity, allowing for optimal performance. Using a birefringent filter and two etalons for wavelength selection, we have observed approximately 200 MHz of tuning via electrooptic modulation of the cavity length. This tuning range appears to be limited by the etalon loss curves and is significantly lower than the 450 MHz free spectral range of the cavity.

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To increase the tuning range to the multi-GHz range, we need to tune the cavity over multiple free spectral ranges without mode hops. We have determined that this can be accomplished by utilizing a special electrooptic etalon, that is tuned synchronously with the cavity. The components for this etalon have been ordered and will be implemented during Phase II.

We have identified a potential method utilizing fiber delay interferometry for locking the ramp rate to ensure reproducible frequency ramps (in conjunction with University of Oregon researchers under Prof. T.W. Mossberg).

5) *Maintained external contacts with Scientific Materials and Montana State University.* The collaborative studies between Scientific Materials and Montana State University have long been important in the development and characterization of new memory materials. For example, measurements by Y. Sun in the laboratory of Rufus Cone indicate that the inhomogeneous linewidth of Eu^{3+}:Y_2SiO_5 is a very strong function of concentration and that the absorption cross sections are strongly polarization dependent. Our results are in qualitative agreement. (A quantitative comparison has not yet been made.)

Personnel Supported:

Alan E. Johnson
Eric Maniloff
Thomas W. Mossberg

Publications:

No peer reviewed publications have been submitted during the time period covered by this report.

Interactions/Transitions:

1. Attended 1997 CEC/ICMC 1997 (Cryogenic Engineering Conference & International Cryogenic Materials Conference) and presented a paper entitled "Cryogenically Cooled Optical Dynamic RAM".

2. Attended 1997 Optical Society of America Annual Meeting and presented a paper entitled "Optical Dynamic RAM: A New Entry in the Memory Hierarchy".

New discoveries, inventions, or patent disclosures:

Novel method of attaining frequency agile performance from a dye laser or other laser with a very broad gain profile.

Novel method of laser stabilization using a fiber interferometer (in conjunction with University of Oregon researchers under Prof. T.W. Mossberg)

Honors/Awards:

None during the period covered by this report.

Future Directions

During Phase II, we will continue development of ODRAM, pushing the limits of the technology to achieve higher single spot bit counts, nonmechanical spatial addressing, dynamic refresh, and parallel data access. Full details of the Phase II work plan were presented in the Phase II proposal.